Cosmogenic activation

What is it?

How does it impact experiments?

How well we can model it?

How to control it?

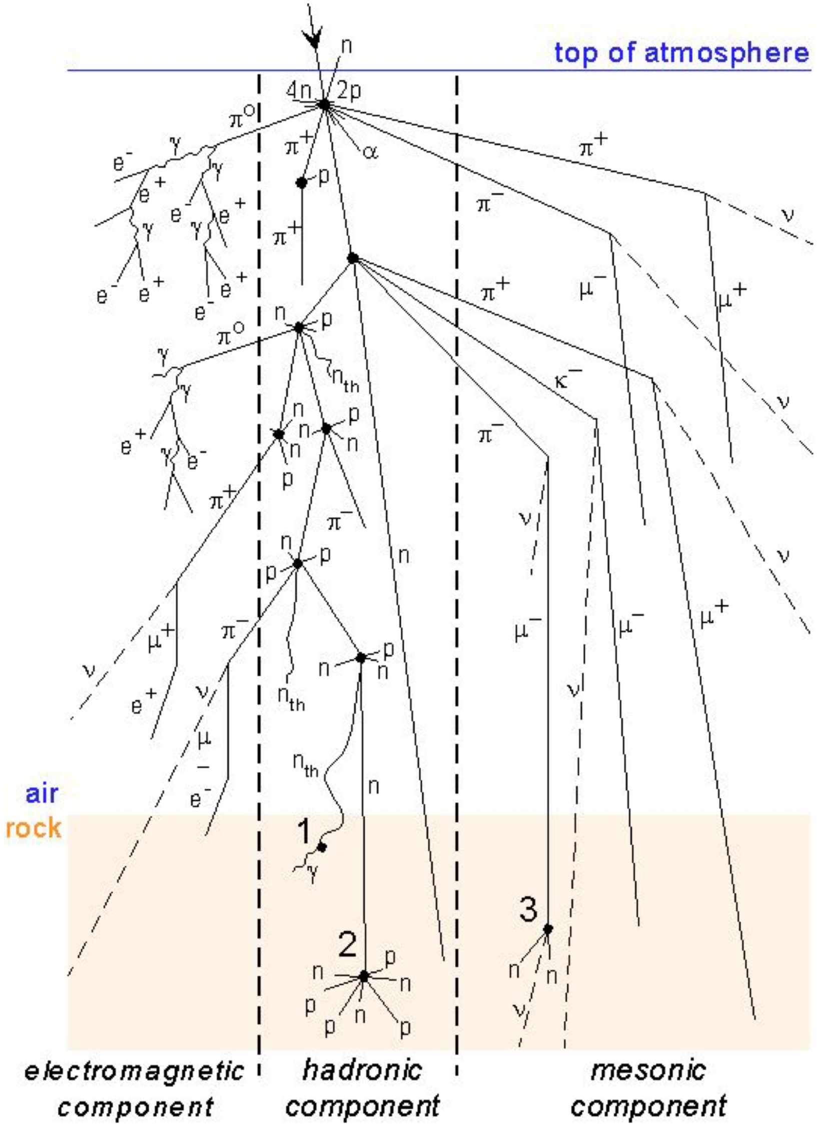
Jules Gascon
(IPNLyon, Université Lyon 1 + CNRS/IN2P3)
.. with help from M. De Jesus & C. Augier

Cosmic Ray interactions

- Electromagnetic component stopped in atmosphere
- Hadronic (n) component penetrates a few m

  $$I(\text{mwe}) \sim I_o\, e^{-\text{mwe}/[1.5\text{m}]}$$

  [^{3}H in rock, arxiv:1607.08770]
- Deep underground, only high-energy muons can produce nuclear reactions
- Neutrinos? [HALO expt…]



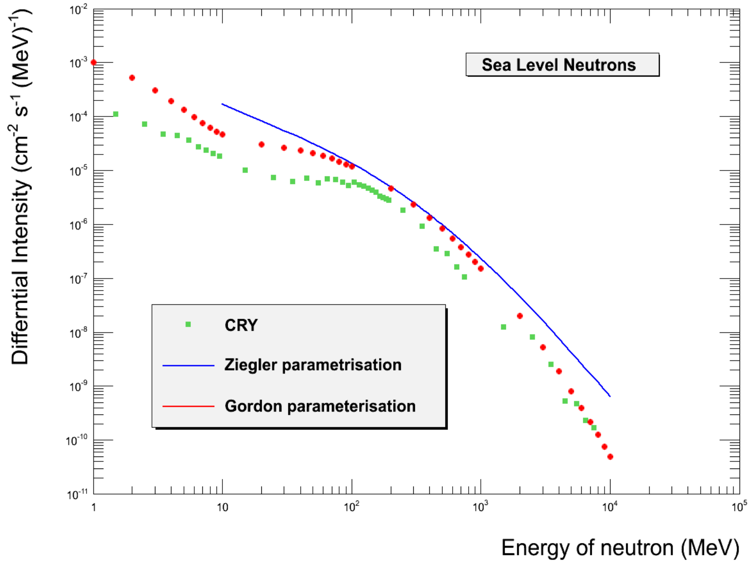
Isotope yield

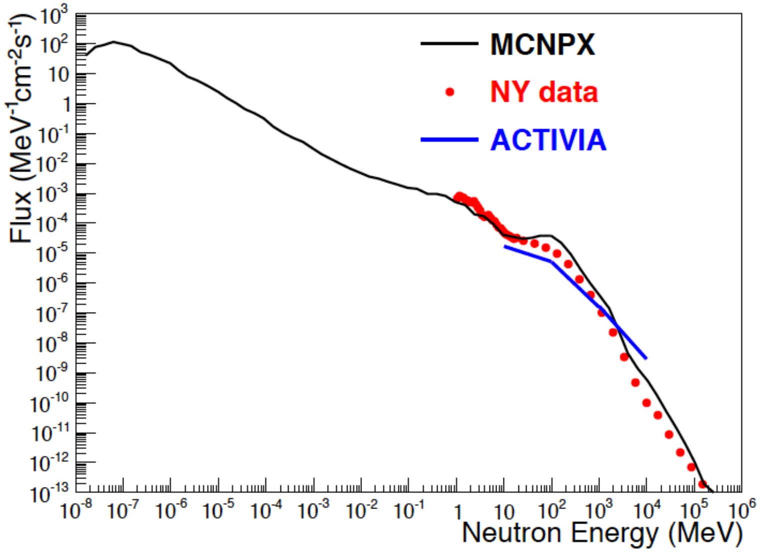
- Cosmic ray flux Φ_0
- Attenuation of flux in matter (mostly: n, μ): $\Phi_{\mu,n}(z)$
- Cross-section σ for production of isotope *X* on a target *Y*
- Production during a time t_{prod} : $\sigma\,\Phi\,(1-\exp(-t_{prod}/\tau))$
- Decay of *Y* during a time t_{decay} : $\exp(-t_{decay}/\tau)$

Uncertainties in neutron flux

- Parameterizations: Gordon (New York data), Ziegler

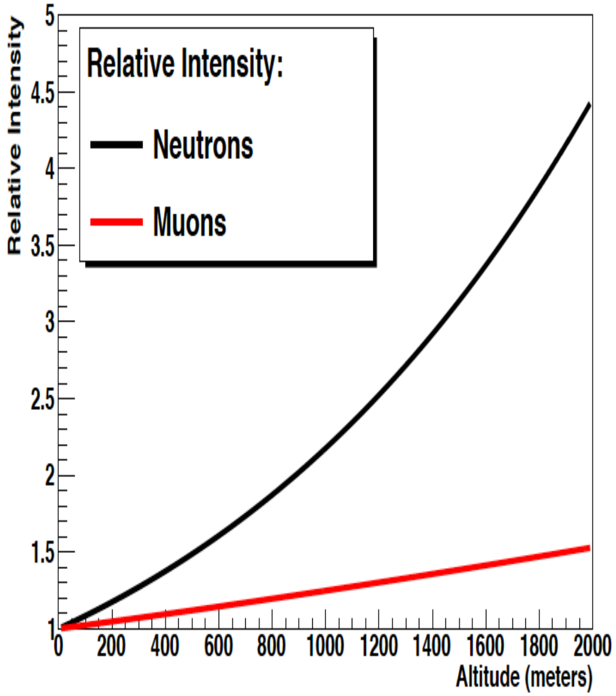
- Models: Activia, MCNPX, COSMO, GEANT4, FLUKA, … (see Kudryavtsev, LRT2017)

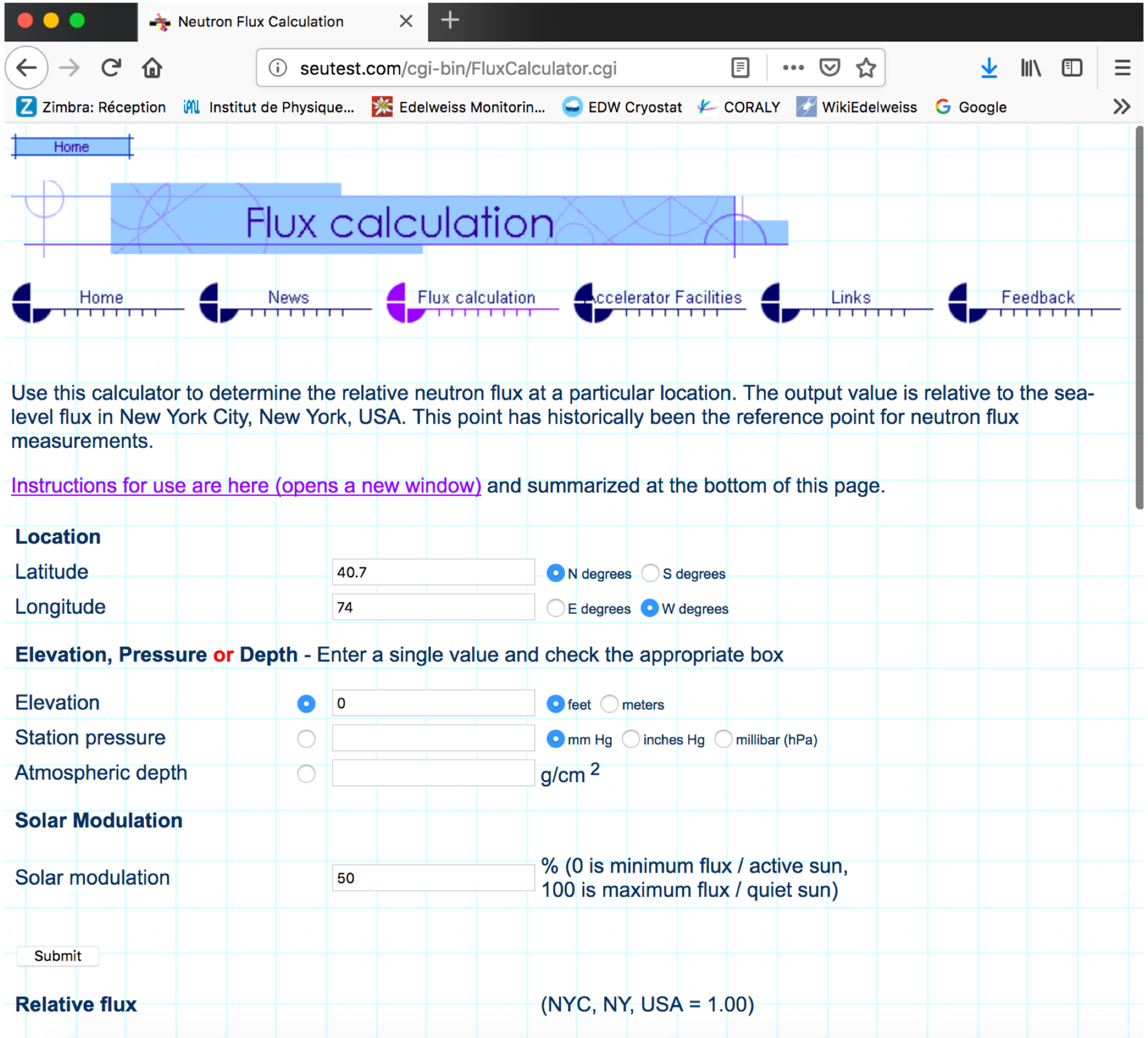




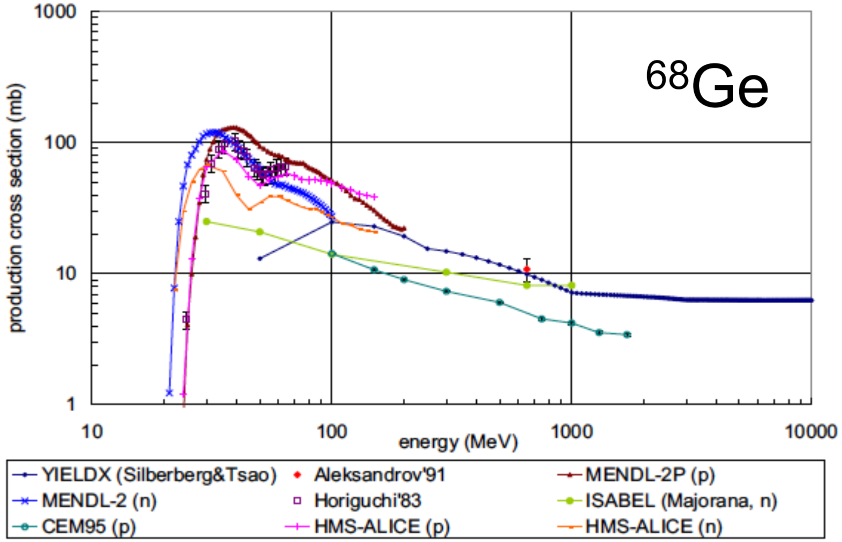
Attenuation of flux

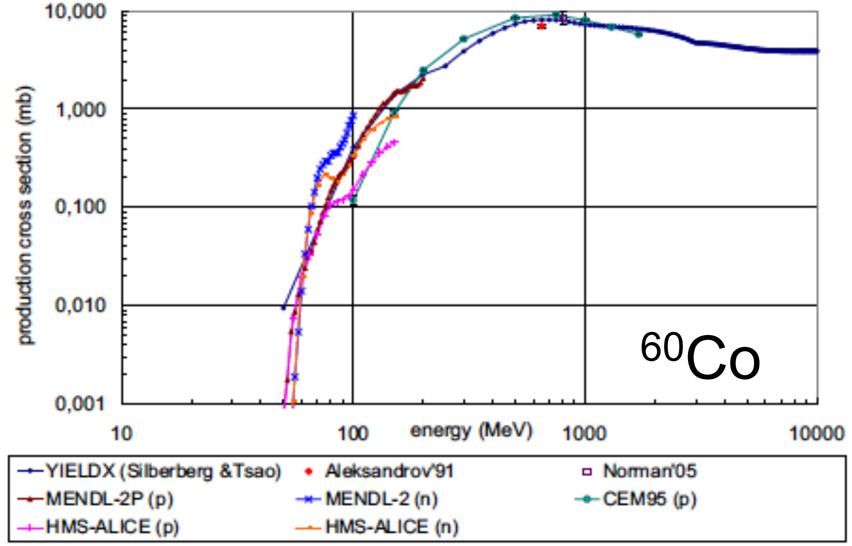
- Neutron flux calculator





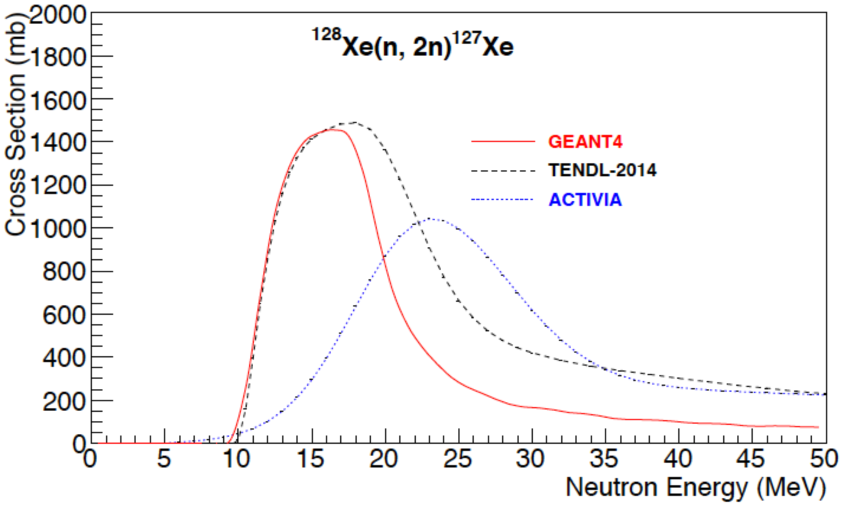
Production Cross-Sections

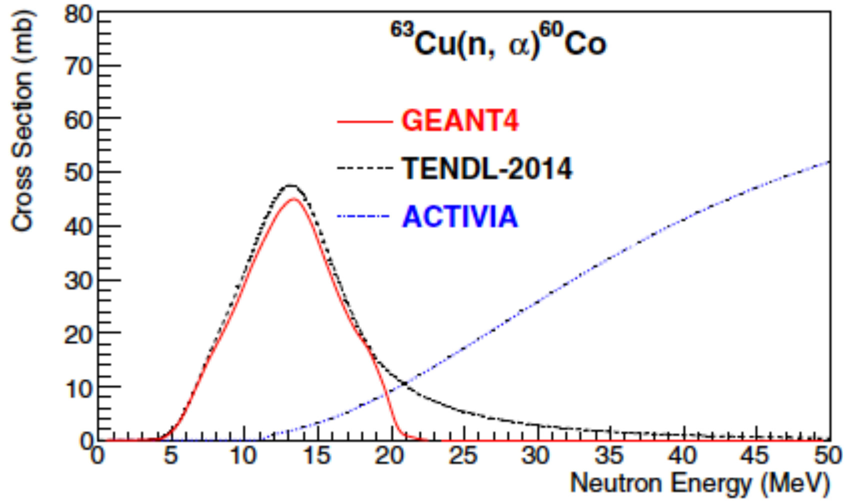




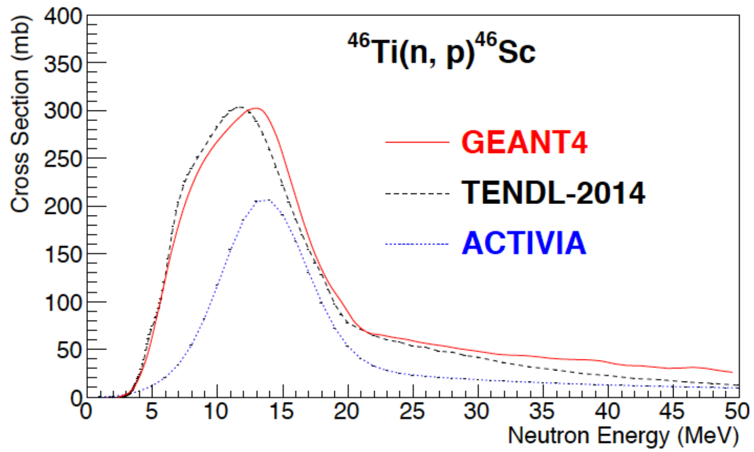
- Production cross-sections (excitation functions) of ^{68}Ge and ^{60}Co in natural Ge (Cebrian et al. Journal of Physics, Conference series, **39** (2006) 344; Cebrian et al. Astroparticle Physics, **33** (2010) 316; Review by Cebrian at LRT2013).
- Cross-sections:
  - Silberberg, Tsao and Barghouty. Astrophys. J., **501** (1998) 911; YELDX.
  - MENDL-2/2P libraries: https://www-nds.iaea.org/publications/iaea-nds/iaea-nds-0136.htm.

Production Cross-Section at Low Energy

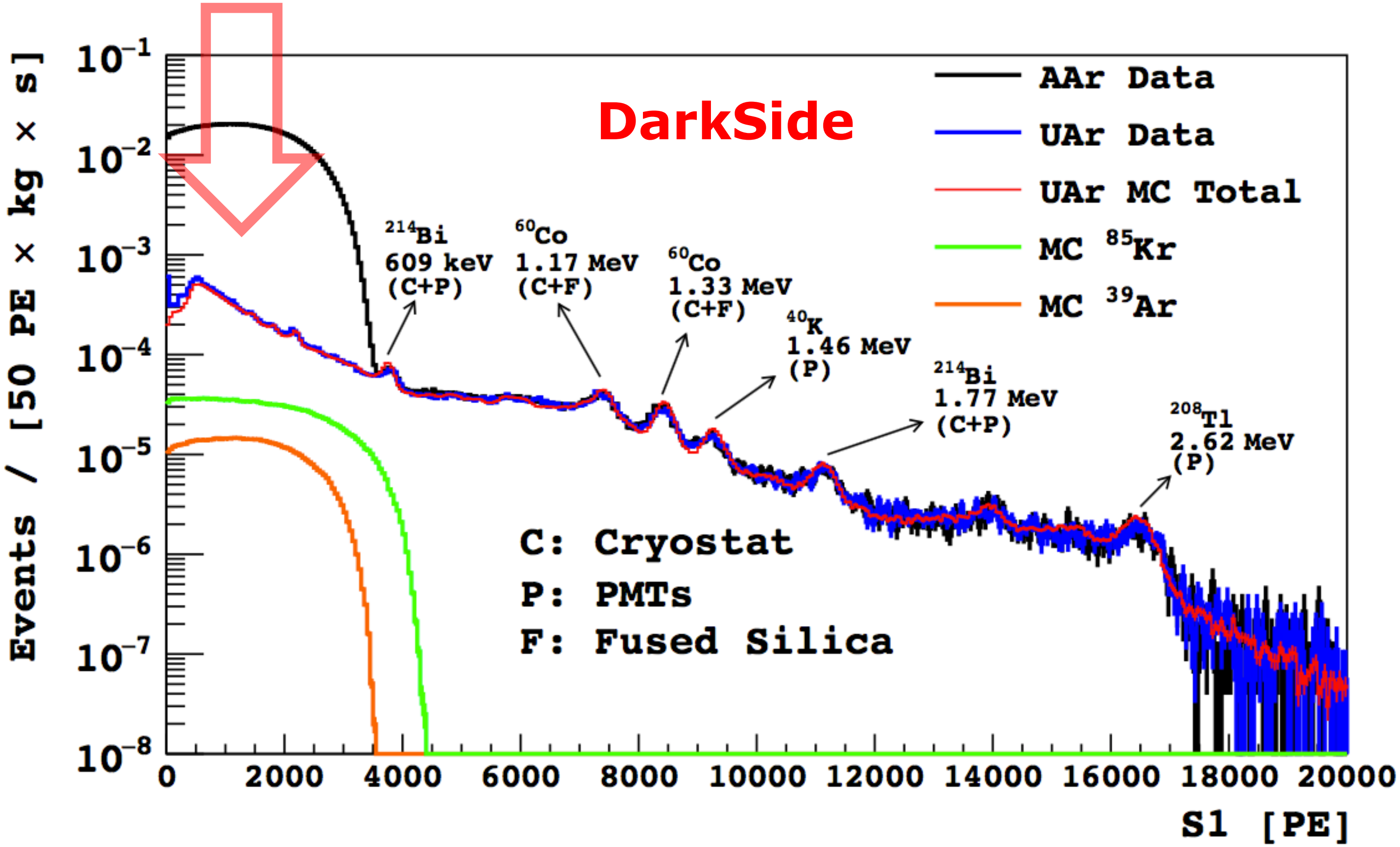




- Evaluated Nuclear Data File – ENDF (used in GEANT4, G4NDL).
- Experimental Nuclear Reaction Data, EXFOR.
- TENDL (-2015) – output from TALYS.
- From Zhang et al. Astroparticle Physics, **84** (2016) 62.
- ACTIVIA (Silberberg and Tsao): J. J. Back and Y. A. Ramachers, Nucl. Instr. and Meth. A586 (2008) 286.



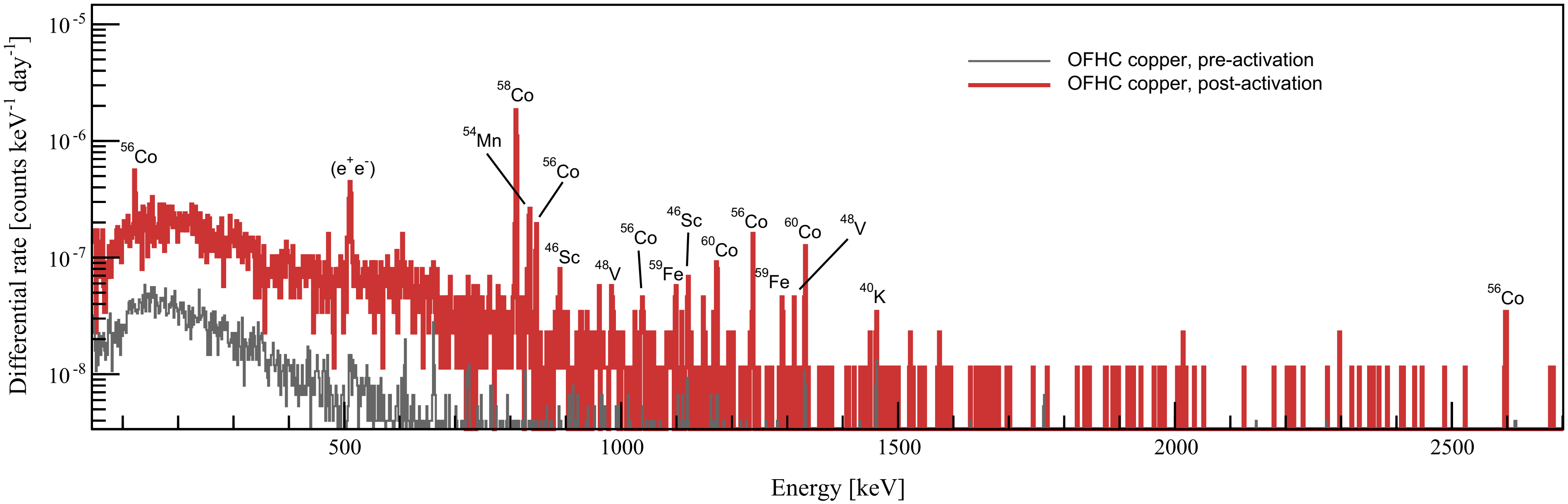
- Huge impact on low-energy background of removal of cosmogenic background of ^{39}Ar



Impact: ^{60}Co activation in Cu

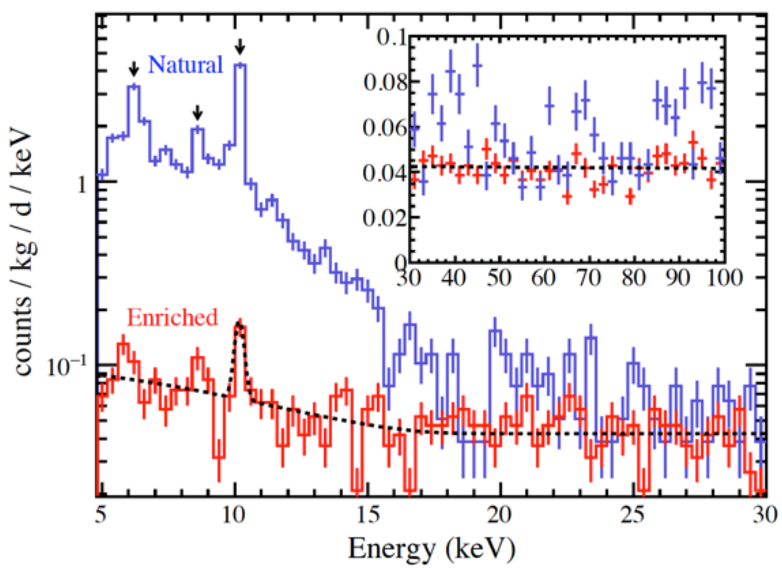
Ex. of measurement: Baudis et al., EPJ C 75 (2015) 485

- Exposure of 10.35 kg Cu (OFHC) to cosmic rays 3470 m above sea level (x11) for 345 days
- ^{60}Co activation (at saturation): 340^{+82}_{-60} μBq/kg (but others: x3)
- Not dominant γ background wrt U/Th + ^{40}K [see eg LUX: AP 62 (2015) 33; Majorana NIMA 828 (2016) 22]… but with efforts



Impact: ^3H in Ge

- ^3H is dangerous for low-energy searches: low end point (18 keV) large half-life (12 y)
- Expected to be the main background for SuperCDMS SNOLAB Ge-HV search for low-mass WIMPs



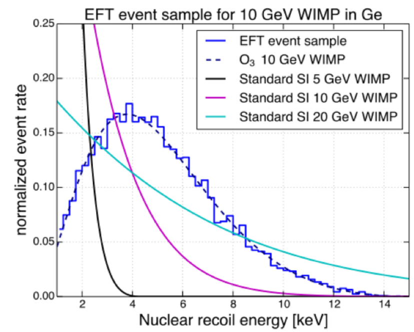
Phys. Rev. Lett. 118, 161801 (2017)

The reduction in the low energy events can be seen between our enriched and natural detectors.

The natural detectors spent significant surface time in Los Alamos and production was not closely tracked.

MAJORANA

Compared to 5-10-20 GeV WIMPs

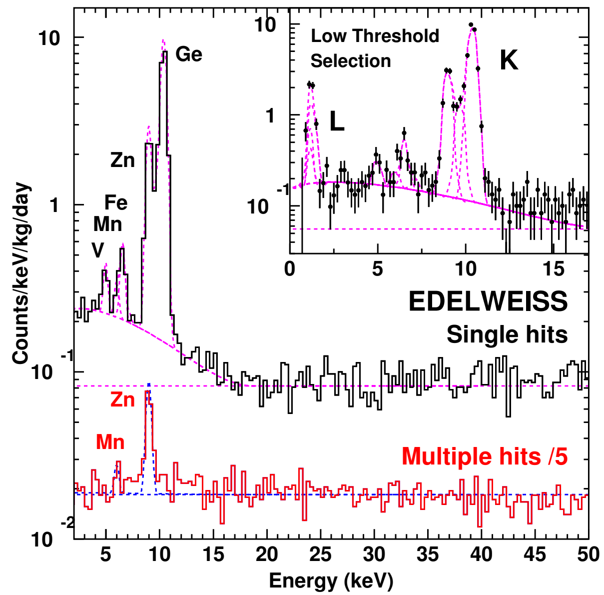


EDELWEISS measurement: 82±21 atom/day/kg

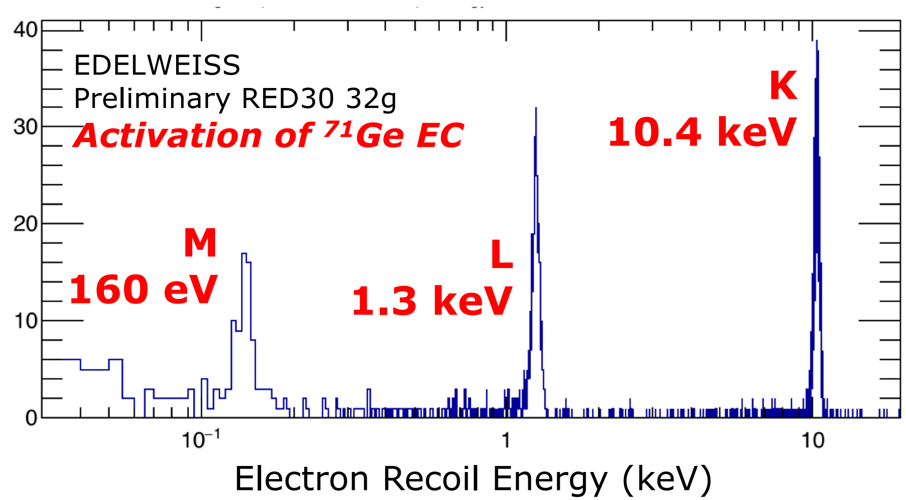
Good Impact? Bulk Calibration…

- Cosmogenic activation is uniform over the entire volume: *useful for low-energy calibration of massive detectors and fiducial volume measurements*

- However thermal neutron activation (here: 71Ge) is more selective & cleaner



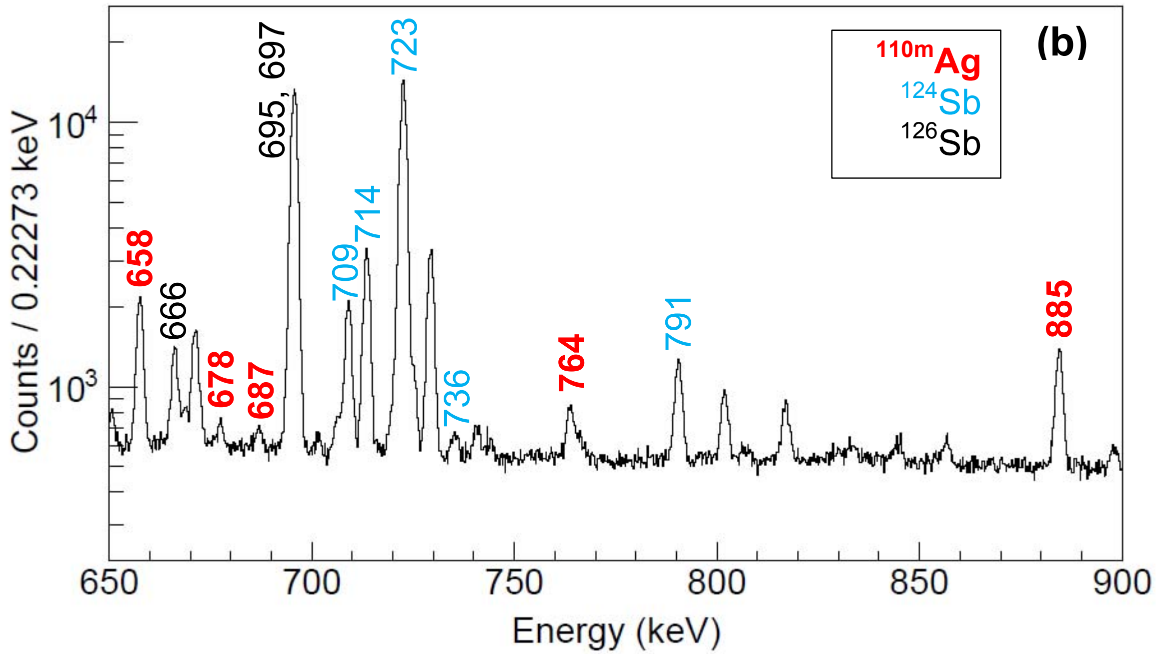
AstroPart. 91 (2017) 51



Production yield measurement in TeO_2

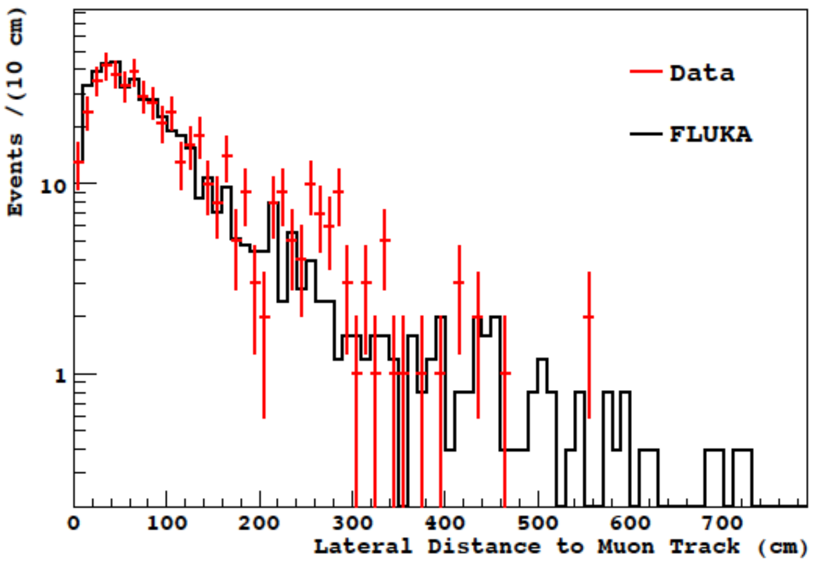
CUORE, PRC 92 (2015) 024620

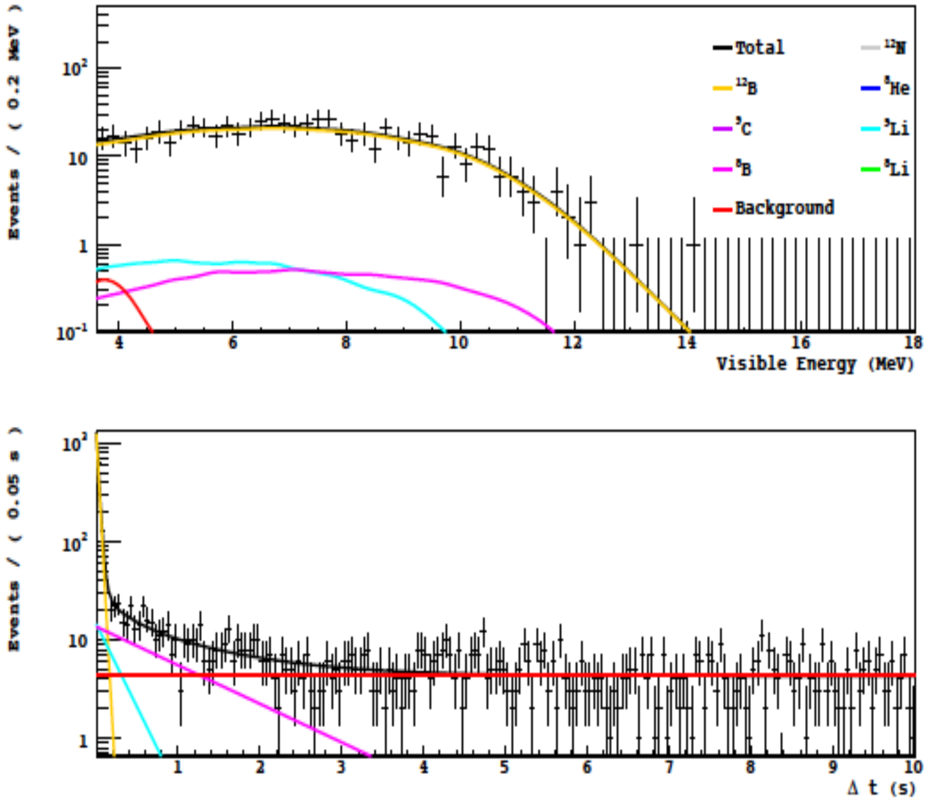
- Replace cosmic rays with (→800 MeV) n and (→28 GeV) p beams
- Measure activation of TeO_2 powder with Ge
- Check that $T_{1/2}$>1y isotopes with Q>2.5 MeV have negligible impact on backgrounds in region of interest for $2\beta0\nu$



Underground Production Measurement

- Kamland, Borexino: measure cosmogenic isotope production correlated with muon track (<E_μ> ~ 270 GeV)
- Ex: Borexino, JCAP 1308 (2013) 049, arXiv:1304.7381



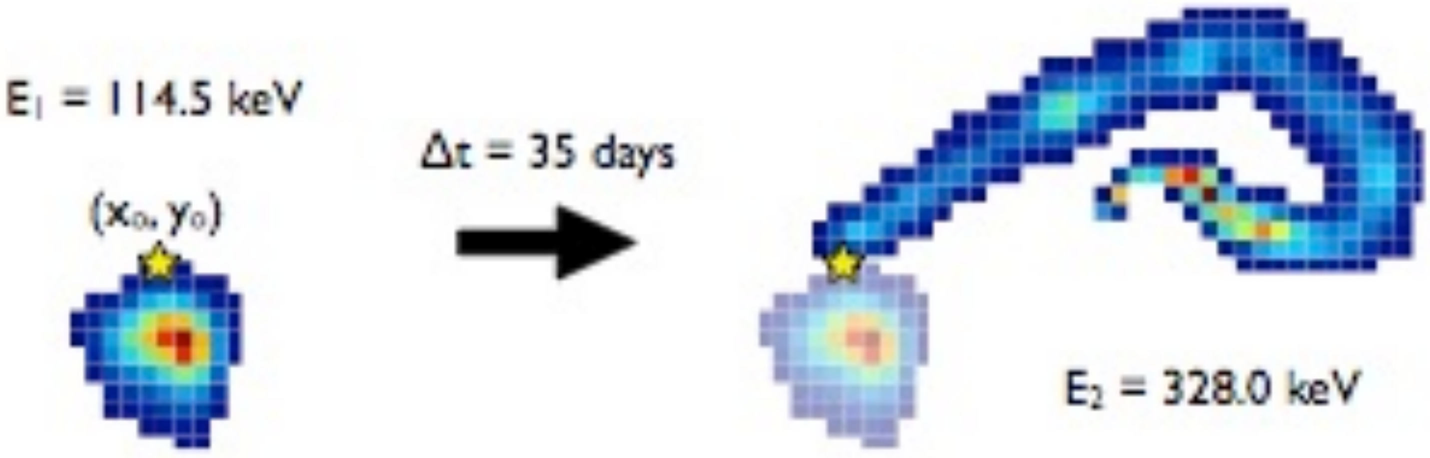


Production yield measurement in Si

- ^{32}Si β^- decay may be an important bkg for CDMS SNOLAB Si-HV
- Origin: spallation of Ar in atmosphere
- Decay cascade:

  $^{32}Si\ \beta^- \Rightarrow {}^{32}P$ Q = 227 keV $T_{1/2}$ = 150 y

  $^{32}P\ \beta^- \Rightarrow {}^{32}S$ Q = 1.7 MeV $T_{1/2}$ = 14 d
- DAMIC CCD: from observed 13 Si/P pairs with <7 pixel separation and <70 days apart, deduce a production rate of 80^{+110}_{-65} atoms/kg/day @95%CL. Reconstruction efficiency: 49%.



Control of exposure

Example: MAJORANA, NIMA 779 (2015) 52

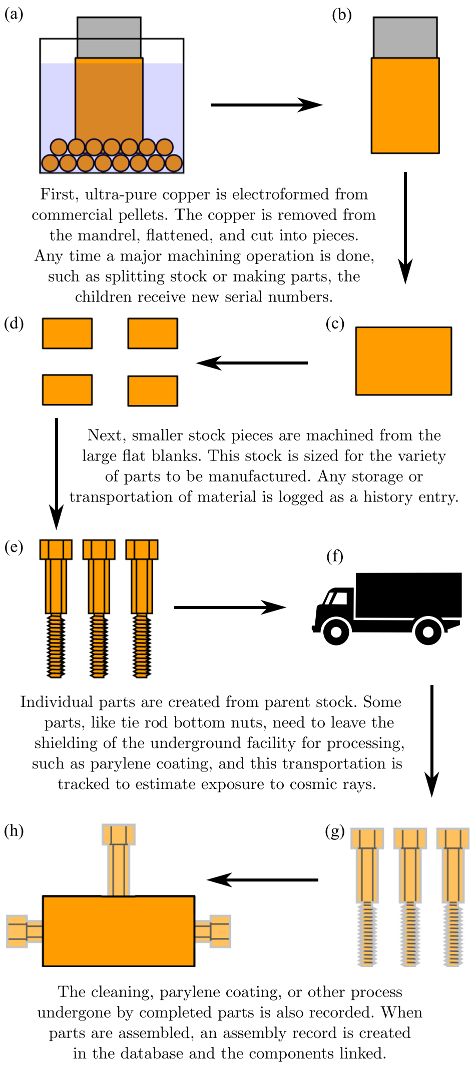
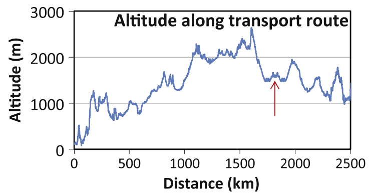


Table 1
FedEx Tracking information (upper left table) and the inferred set of transportation and storage record entries for the PTDB (lower table). All dates occur in the calendar
2012. The figure shown in the upper right presents the altitude variation experienced by the part during shipment, with a notable day long stop in Denver, CO located at
red arrow.

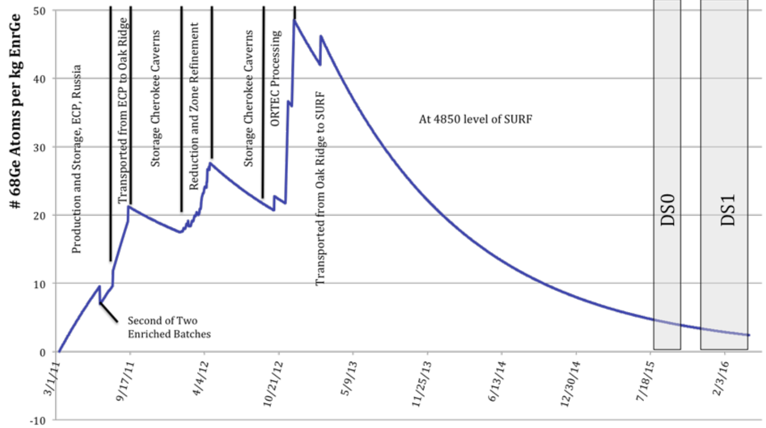
FedEx Tracking data (reverse chronological order)

Date, Time	Activity	Location
Jun 13, 12:06	Delivered	Lead, SD
Jun 13, 10:37	Out for delivery	Rapid City, SD
Jun 13, 8:50	At local facility	Rapid City, SD
Jun 13, 5:00	At local facility	Rapid City, SD
Jun 12, 21:10	In transit	Denver, CO
Jun 11, 8:32	In transit	Boise, ID
Jun 9, 2:50	In transit	Hermiston, OR
Jun 8, 20:45	Left FedEx origin	Pasco, WA
Jun 8, 14:23	Picked up	Richland, WA



Parts Tracking Database records information (chronological order)			Exposure calculation
Record Type	Start – End (Date, Time) – (Date, Time)	Movement or Location (City, State)	Sea-level Equivalent Exposure (hours)
Transport	Jun 8, 14:23 PDT – Jun 8, 14:43 PDT	Richland, WA → Pasco, WA	0.4
Storage	Jun 8, 14:43 PDT – Jun 8, 20:45 PDT	Pasco, WA	4.6
Transport	Jun 8, 20:45 PDT – Jun 8, 21:30 PDT	Pasco, WA → Hermiston, OR	0.9
Storage	Jun 8, 21:30 PDT – Jun 9, 2:50 PDT	Hermiston, OR	6.2
Transport	Jun 9, 2:50 PDT – Jun 9, 8:03 MDT	Hermiston, OR → Boise, ID	11.2
Storage	Jun 9, 8:03 MDT – Jun 11, 8:32 MDT	Boise, ID	114.9
Transport	Jun 11, 8:32 MDT – Jun 11, 20:42 MDT	Boise, ID → Denver, CO	95.2
Storage	Jun 11, 20:42 MDT – Jun 12, 21:10 MDT	Denver, CO	133.5
Transport	Jun 12, 21:10 MDT – Jun 13, 3:12 MDT	Denver, CO → Rapid City, SD	29.8
Storage	Jun 13, 3:12 MDT – Jun 13, 10:37 MDT	Rapid City, SD	21.1
Transport	Jun 13, 10:37 MDT – Jun 13, 11:34 MDT	Rapid City, SD → Lead, SD	2.9
Storage	Jun 13, 11:34 MDT – Jun 13, 12:06 MDT	Lead, SD	2.7

Estimations made from measured cross section and database information.



Control

- Production in underground lab
- Storage in underground lab
- Adapt production process to reduce exposure

- Shallow labs? (remove hadronic component)

- Measurements to further tests present codes